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Art. IV.—*Note on the Reflection of X-rays from Glass and Quartz.*

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The reflection of X-rays has been observed by the authors for glancing[1] angles up to 45° from glass and 40° from quartz, the critical or limiting angle not having been observed. The X-rays incident on the glass or quartz are, it is believed, heterogeneous X-rays of wave-length in the region of about 50 Å.U. The most intense wave-length in the incident radiation is probably the $K\alpha$ line of carbon of 45 Å.U. wave-length.

That X-rays incident at angles of less than 1° are reflected by glass and by metals is now a well-known phenomenon (1), but that a wave-length of about 50 Å.U. would be reflected when incident at about 40° is not to be expected from the observations already made. Holweck claims to have observed the reflection of long X-rays from polished bronze at 11·7° and 16·2° (2). Dauvillier (3) remarks that he observed in this region (50 Å.U.) optical reflection from glass and from a thin film of melissic acid on lead.

Assuming that we have correctly interpreted the preliminary observations which we have made, it can be concluded that X-rays can be reflected from spherical surfaces and brought to a focus, which will make new methods for the study of long X-rays possible.

Experiments.

The apparatus used in our experiments is a vacuum spectrograph in which the crystal has been replaced by a piece of optically flat plate glass or quartz which acts as the reflector of the X-rays. The target, Wehnelt cathode, the reflector, the camera and photographic film are in the same vaccum.[2] The X-rays

1.—All angles of incidence and reflection stated are glancing angles.
2.—The spectrograph in the use of a common vacuum for the "X-ray tube" and spectrograph is similar to that described by Shearer, *Phil. Mag.*, Oct., 1927.

emitted by the target pass through a circular hole in a shield and then fall on the reflector. The reflected rays pass through a slit into a camera and fall on a Schumann film. Copper and carbon targets have been used. The difference of potential between the cathode and the copper target was at first up to 10,000 volt rectified A.C. In later experiments, the P.D. between the carbon target and the Wehnelt cathode has been about 375 volt given by a battery.

The photographic film on development shows a slit image of the focal spot on the target. This slit image is the same whether it is taken direct, without the glass or quartz reflector, or with the reflector, except that in the latter case there is lateral inversion of the image. The angle of incidence is accurately equal to the angle of reflection. Using the copper target reflection up to an angle of 29° from glass was observed, and with the carbon target rays reflected at 45° from glass and 40° from quartz have been photographed. In each case, this angle is the largest attainable with the spectrometer. An exposure of 1200 milliampere second and a potential difference of 375 volt gives a well-defined image of the focal spot on Schumann film.

Estimates of intensity with the Schumann film are difficult to make. The ratio of intensity of the reflected beam to that of the incident beam in the case of the graphite target is of the order of $\frac{1}{2}$ up to 30° glancing angle. At 40° incidence this ratio had considerably diminished.

The evidence that the radiation is optically reflected appears to be conclusive.

What is the nature of the radiation which is reflected?

As the photographic film is enclosed and placed opposite the slit (0·05 mm. wide) in a metal box which is at the potential of the negative end of the filament of the cathode, the rays cannot be cathode rays.

The radiation—

(*a*) is emitted, as shown by the slit images, from the same focal spot as that from which short wave X-rays[3] were proved to be emitted in other experiments;

(*b*) penetrates aluminium foil[4] 0·0006 mm. thick, about 1% of the incident radiation being transmitted (this foil was tested and found to absorb visible light);

(*c*) is absorbed by glass and by fluorite;

(*d*) is emitted by a carbon target on which 375 volt electrons are incident;

3.—That these rays were X-rays was fully verified by wave-length measurement.

4.—In a previous paper by one of the authors (Shearer, *P. M.* Vol. IV., p. 747, 1927), two thicknesses of aluminium foil were not found to be transparent to X-rays in this region. It should be noted that only one thickness of foil is penetrated in the observation recorded above, and all the conditions in these experiments tend to give an incident beam of increased intensity.

(*e*) is not emitted when the filament is hot, and no potential is applied between it and the anode;

(*f*) is in its action on Schumann film approximately proportional to the exposure measured in milliampere second at constant voltage.

If the radiation is not X-rays emitted according to the usual laws[5] connecting wave-length with applied potential, it can be longer in wave-length than is given by those laws; but it would appear to be very improbable that it is shorter. The observation (*c*) above excludes the assumption that the radiation is in the range of about 8000 down to 1200 Å.U. Observation (*b*) excludes the region longer than 8000 Å.U. It remains to consider the region from about 100 to 1200 Å.U. All the evidence from the observations of Schumann, Lyman, Millikan and Holweck[6] show that radiation in this region is highly absorbed by all forms of matter, and thus (*b*) above excludes the Millikan and Lyman regions of the spectrum. Observation (*e*) confirms that the radiation is not one emitted by a hot body at a temperature up to 1200°C., the highest temperature of the filament. The absorption measurement in (*b*) is consistent with the radiation being of wave-length from 50 to 80 Å.U., assuming the λ^3 law of absorption. Observation (*f*) implies that the radiation is produced by the incidence of electrons on the target.

Taken as a whole, the evidence strongly supports the view that X-rays of wave-length about 45 Å.U. can be reflected at angles up to 40° from glass and quartz.

The Lorentz dispersion formula in the form

$$\delta = 1 - \mu = \frac{e^2}{2\pi m} \sum \left(\frac{n_s}{\nu^2 - \nu_s^2} \right) = 4{\cdot}478.10^{-14} \sum \left(\frac{n_s}{\nu'^2 - \nu_s'^2} \right)$$

where e and m are the charge and mass of the electron, n_s is the number of electrons per unit volume of natural frequency ν_s (wave-number ν'_s) and ν is the frequency of the incident radiation (wave-number ν'), has been shown to give, in the case of X-rays, positive values of δ which are confirmed by experiment (1). Total reflection is therefore to be expected for radiation incident on substances for which μ is less than unity at a glancing angle less than a certain critical value. This was first observed by Compton (1) from surfaces of glass, silver, lacquer and calcite.

5.—These laws have been assumed by Holweck for the range 44 to 300 A.U. "De la Lumière aux Rayons X", Chap. III.

6.—Holweck finds that μ/ρ for celluloid increases rapidly up to about 300 A.U., becomes a maximum at about 320 A.U., and then rapidly decreases toward 1200 A.U.

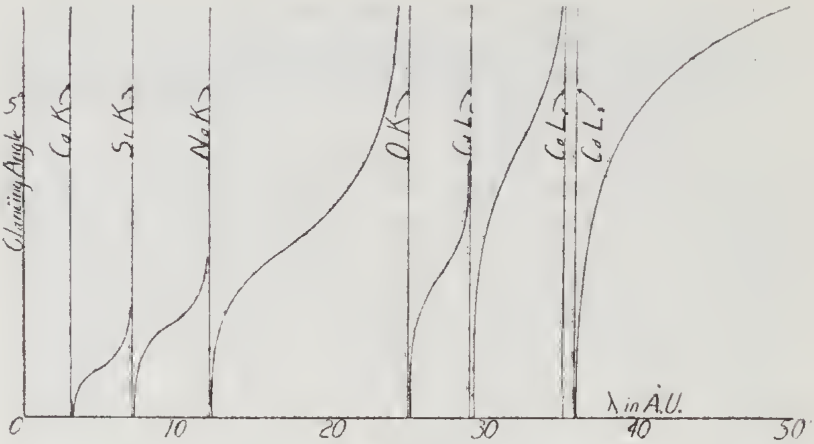

FIG. 1.

In the figure the critical glancing angle for glass θ_c is plotted against wave-length in Å.U. of the incident radiation, where θ_c is obtained from the relation $\cos \theta_c = \mu$ and μ is calculated from the Lorentz formula. ν_s is obtained from the following data (assumed) :—

Density of glass:	3 gm./cc.
Composition:	71% SiO_2
	15% CaO
	14% Na_2O.

Number of electrons per atom:

	K	L	M	N
Si(14)	2	8	4	—
Na(11)	2	8	1	—
Ca(20)	2	8	8	2
O(8)	2	6	—	—

The following values of $\lambda_s \left(= \frac{1}{\nu_s}\right)$ in Å.U. were adopted:

	K	L
Si(14)	7	112
Ca(20)	3	33
Na(11)	12	322
O(8)	25	717

The results obtained in this paper do not appear to be reconcilable with this curve.

We have to thank Messrs. H. Massey and C. Mohr for computing the data shown in Fig. 1.

REFERENCES.

(1) A. H. COMPTON. X-rays and Electrons, Chap. VII.
(2) HOLWECK. De la Lumiere aux Rayons X, p. 85, Paris, 1927.
(3) A. DAUVILLIER. *Journal de Physique,* viii. (1). 1927.